MINISTRY OF HEALTH

TRIAL CASE LENSES

Report of a Committee appointed by the Minister of Health

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Committee on Trial Case Lenses

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Report of the Committee on Trial Case Lenses

TO THE RT. HON. R. H. TURTON, M.P.,
Minister of Health.

Sir,

We were appointed by your predecessor in December, 1954, as a Committee with the terms of reference " to review standards for trial case lenses and the method of measuring lens powers and to make recommendations ". We have held three meetings and now have the honour to present a unanimous report.

The ophthalmic trial case, containing a graduated series of spherical and astigmatic lenses as well as prisms and other accessories, is used to estimate errors of refraction and anomalies of muscle balance. It first appeared in approximately its present form about ninety years ago, when the introduction of routine testing for astigmatism brought complexity into what had hitherto been a comparatively simple process.

The design of a piece of equipment so fundamental to the prescribing of spectacles clearly deserves the most careful study to ensure that it fulfils its purpose with the maximum of efficiency.

SCOPE OF REPORT

The two questions contained in our terms of reference are closely related and were both considered from the same standpoint, the object we had in view being to ensure that, as far as possible, the effective power of the lenses employed should be accurately known and the spectacles accurately dispensed.

An inquiry into present practice made it apparent that appreciable errors can arise from various sources including

(*a*) discrepancies between the two principal methods of measuring lens powers, i.e., neutralisation and the use of a vertex focimeter,

(*b*) failure to appreciate the significance of the " vertex distance " or lens-eye separation,

(*c*) discrepancies between various existing types of trial case lenses.

Our report is in two parts. In Part I we set out the reasons which have led us to recommend the adoption of the back vertex measurement of all lens powers, and we also give our recommendations on the recording of the vertex distance. Part II of our report deals with trial case lenses under the following main headings:

1. Review of previous standards.
2. Existing types of trial case lenses.
3. System of numbering.
4. Lens form and aperture.
5. Prism units.
6. Details of marking.
7. Standards and tolerances.
8. Standard conditions for laboratory testing of lenses.
9. Calibration and use of focimeters.
10. Refracting Units (Refractor Heads).

We would wish to put on record our warm appreciation of the services of the officials of the Ministry of Health who helped us so efficiently in our work; our debt to both Mr. A. T. Gerard and Mr. A. G. Bennett is great. Indeed, without the help of Mr. Bennett this report could not have materialized in the form it has, for we depended to an unusual degree on his encyclopaedic knowledge of optics as well as his understanding of the technical problems involved. For the care and trouble he took in guiding and assisting us, we would like to record our thanks.

PART I

Measurement of Lens Powers

1. DEFINITIONS

The dioptric system relates the power of a lens to its focal length but this latter term requires a precise definition. In technical optics generally the " focal length " of a lens is understood to mean its *equivalent* focal length, measured from a hypothetical point on the optical axis termed the " unit " or " principal " point; and its " power " is understood to mean its *equivalent* power, based on the equivalent focal length.

The power so defined is not, however, a significant property of spectacle lenses except for its bearing on magnification. In practice it is more convenient to measure the focal length from a tangible point such as the vertex of one surface. The " back focal length " is accordingly defined as the distance from the vertex of the back surface to the principal focus for parallel light incident on the front surface; and the " back vertex power " is the reciprocal of this distance in metres. The " front focal length " and the " front vertex power " of a lens are defined in an analogous manner.

2. ADVANTAGES OF A BACK VERTEX NUMBERING

The practice of numbering ophthalmic lenses according to their back vertex power seems to have originated over 40 years ago. The great advantage of this system is that it enables the focal properties (for distant vision) of any ophthalmic lens or lens combination to be expressed in terms of only two quantities: its back vertex power and the distance of the back vertex from the cornea (known as the " vertex distance ").

A back vertex numbering thus eliminates complications which would otherwise arise in dispensing. For example, although two lenses may differ considerably in form and thickness, they will equally correct a refractive error if their back vertex powers are the same, the vertex distance being unchanged. Moreover, should any change in the vertex distance be necessary, it becomes a simple matter to calculate the compensating modification of power.

3. PRACTICAL METHODS OF MEASUREMENT

Two methods of verifying lens powers are in current use by ophthalmic practitioners and dispensers:

(*a*) neutralisation with trial case lenses,

(*b*) the use of a vertex focimeter.

This latter instrument, which is also known under a variety of trade names, enables either the front or the back vertex power of a lens, together with the axis direction and any prismatic effect, to be measured both quickly and accurately. On the other hand, the practice of neutralisation is attended by certain limitations which ought to be briefly mentioned.

Two lenses are said to neutralise if a test object exhibits no apparent movement when the lenses are moved laterally across the line of sight. If the object is sufficiently distant to be considered at infinity, the condition for neutralisation is that the two lenses form an afocal or telescopic system with its principal points at infinity. Since parallel light both enters and leaves the system, a lateral displacement of the lenses can produce no apparent movement of the distant object. Provided that the two lenses are in central contact, it may then be inferred that their powers are equal and opposite when *measured at the vertex of the adjacent surfaces.*

Unfortunately, neutralisation with ordinary trial lenses cannot conveniently be employed to measure the back vertex power of " curved " lenses because the trial lens cannot be placed in contact with the back vertex of the lens to be verified. It is usually held next to the *convex* surface of the lens under test which means that the quantity measured is the *front* vertex power.

The difference between the front and back vertex powers of a number of typical lenses calculated for a refractive index of 1·523, is shown in Table I. It will be noted that the front vertex power is invariably the weaker of the two.

TABLE I

DIFFERENCE BETWEEN BACK AND FRONT VERTEX POWERS

Back Vertex Power (D)	Form of Lens	Centre Thickness (mm.)	Nominal Front Surface Power (D)	Front Vertex Power (D)	Difference (D)
− 20·00	Plano-cc.	0·5	Plano	− 19·87	0·13
− 15·00	Plano-cc.	0·5	Plano	− 14·93	0·07
− 10·00	Plano-cc.	0·6	Plano	− 9·96	0·04
− 10·00	Meniscus	0·6	+ 3·00	− 9·93	0·07
− 8·00	Meniscus	0·7	+ 3·00	− 7·94	0·06
− 6·00	Meniscus	0·7	+ 3·00	− 5·96	0·04
− 4·00	Meniscus	1·0	+ 6·00	− 3·93	0·07
− 2·00	Meniscus	1·3	+ 6·00	− 1·98	0·02
+ 2·00	Meniscus	2·6	+ 8·00	+ 1·95	0·05
+ 4·00	Meniscus	3·5	+10·00	+ 3·86	0·14
+ 6·00	Meniscus	4·4	+12·00	+ 5·69	0·31
+ 8·00	Meniscus	5·4	+14·00	+ 7·46	0·54
+ 8·00	Plano-cx	5·4	+ 8·00	+ 7·78	0·22
+10·00	Plano-cx	5·8	+10·00	+ 9·63	0·37
+15·00	Plano-cx	6·5	+15·00	+14·10	0·90
+20·00	Plano-cx	7·2	+20·00	+18·28	1·72

It will also be noted from this table that the difference varies with the centre thickness and curvature of the lens. Since both these factors are operative, a simple conversion table cannot be provided.

With concave lenses generally and with convex lenses of low power, the difference between the two vertex powers is seen to be negligible. Within these limits, neutralisation undoubtedly provides an adequate means of verifying the power of a lens. On the other hand, when the power begins to exceed +2·00 D the difference can no longer be ignored, while with very high positive powers it may easily exceed a dioptre. With compound lenses, the cylinder power is affected as well as the spherical power. For example, a curved lens of average thickness measuring +4·00 sph. +4·00 cyl. at the back vertex would have a front vertex power of approximately +3·75 sph. +3·75 cyl.

These figures lead to the conclusion that the method of measurement is not an academic question but a matter of considerable practical importance.

Further errors may be introduced if several neutralising lenses have to be used simultaneously, or if the test object is relatively close to the observer. In this latter case the condition for neutralisation is no longer that the two lenses form an afocal system, but a system of some low but finite power with its first principal point in the plane of the test object. As an example, if a +20 D and a −20 D lens from a full-aperture symmetrical-form trial set neutralised perfectly for an object at infinity, an apparent error of approximately 0·12 D would result if the test object were placed at 60 cm. At 6 metres, however, the error would not exceed 0·02 D.

4. THE CASE FOR STANDARDISING BACK VERTEX MEASUREMENT

We summarise below three of the impressive arguments which can be advanced in favour of standardising the back vertex method of measurement:

(*a*) As will appear from Part II of this report, most of the trial case lenses made in this country during the past 40 years have been numbered on systems which are either identical with or closely approximate to a back vertex numbering. This reason alone is sufficient for recommending that the lenses subsequently dispensed be measured on the same basis.

(*b*) The advantages of a back vertex numbering have led to its becoming the standard accepted in most countries.

(*c*) There is evidence that the industry in this country would now welcome back vertex standardisation. Nearly all manufacturing firms, of whatever size, are to-day equipped with focimeters. Most of the mass-produced glass lenses, and all plastic lenses, are already made to a back vertex numbering.

We appreciate that although many ophthalmic practitioners already possess a focimeter and have adopted back vertex measurement as a matter of routine, a number remain who rely on neutralisation and may expect the lenses dispensed to their prescriptions to be correct to front vertex measurement. Nevertheless we should like to emphasize the point that neutralisation does not measure the really significant quantity and that a lens, even though it neutralises correctly, may be very far from reproducing the effect intended.

It is therefore our unanimous recommendation that the back vertex system of expressing and measuring lens powers become the accepted standard; and we strongly urge practitioners who have not already done so to adopt this system in their own interests.

We understand that no difficulty is likely to arise through a shortage of suitable instruments. At least four British firms have already produced accurate focimeters suitable for the use of ophthalmic practitioners and dispensers.

5. RECORDING THE VERTEX DISTANCE

If the lens dispensed is not fitted at the same distance from the cornea as the rear lens used in testing, its effective power at the cornea may differ by a significant amount from that of the trial lens or lens combination.

Many practitioners aim at placing the rear trial lens so that it just clears the eyelashes. Then, on the assumption that the lens dispensed is also fitted so as just to clear the lashes, no discrepancy can arise.

It occasionally happens, however, that the trial lens cannot be placed in the desired position close to the eye, in which case the vertex distance may undergo a considerable change when the correcting lens is subsequently fitted.

To compensate for such a change, the alteration in the distance should be added to or subtracted from the back focal length of the trial lens combination: the modified power required to reproduce the original effect can then be deduced.

Table II shows in skeleton form the modifications rendered necessary by various changes in the vertex distance for a wide range of lens powers.

TABLE II

MODIFIED POWERS REQUIRED TO COMPENSATE FOR A DECREASE IN THE VERTEX DISTANCE

Power of Trial Lens (D)	Decrease in the Vertex Distance				
	2 mm.	4 mm.	6 mm.	8 mm.	10 mm.
− 20·00	− 19·23	− 18·52	− 17·86	− 17·24	− 16·67
− 16·00	− 15·50	− 15·04	− 14·60	− 14·18	− 13·79
− 12·00	− 11·72	− 11·45	− 11·19	− 10·95	− 10·72
− 8·00	− 7·87	− 7·75	− 7·63	− 7·52	− 7·41
− 4·00	− 3·97	− 3·94	− 3·91	− 3·88	− 3·85
+ 4·00	+ 4·03	+ 4·07	+ 4·10	+ 4·13	+ 4·17
+ 8·00	+ 8·13	+ 8·26	+ 8·40	+ 8·55	+ 8·70
+12·00	+12·30	+12·61	+12·93	+13·27	+13·64
+16·00	+16·53	+17·09	+17·70	+18·35	+19·04
+20·00	+20·83	+21·74	+22·73	+23·81	+25·00

A similar table applying to increased vertex distances could be compiled by merely changing all the signs in Table II.

These figures demonstrate that a prescription of high power is not complete unless it includes the vertex distance.

We understand that in some Continental countries the vertex distance is recorded as a matter of routine, practitioners being equipped with a simple instrument (the Wessely keratometer) for taking this measurement. Instruments for this purpose are available from British manufacturers, and some trial frames are provided with a scale at the side to facilitate the estimation of the vertex distance.

Because of the serious discrepancies which could otherwise occur, we consider it desirable that the practice of recording the vertex distance should be taught and followed in this country; and we accordingly recommend that the vertex distance be included in the prescription whenever the power exceeds 5·00 dioptres and even on lower powers when a significant change in the vertex distance may be expected.

It is to be understood that the onus is on the dispenser to determine whether there will be any change in the vertex distance, and if so, to modify the prescribed power accordingly.

PART II

Trial Case Lenses

1. REVIEW OF PREVIOUS STANDARDS

(a) *The Optical Society's Standards* (1908)

The first standard for trial case lenses was published in 1908 by the Optical Society, London. It was drafted by a Sub-Committee of the Society with assistance from the National Physical Laboratory and under the chairmanship of Sir William Christie, Astronomer Royal.

According to these recommendations, all spherical lenses were to be symmetrical in form (equi-convex and concave) and of full aperture (approx. 36 mm. lens size). The negatives were to be marked with their *equivalent* power and the positives made to neutralise the corresponding negatives. Tables of standard thicknesses and requisite surface powers were given.

Although at that date back vertex conceptions had not become generally familiar, the system of numbering recommended by the Optical Society closely approximates to a back vertex numbering. The back focal length of the negatives exceeds the equivalent focal length only by one-third of the lens thickness, and so the marked power is only negligibly greater than the back vertex power. Furthermore, as the positives are designed to neutralise the corresponding negatives, their vertex powers must be the same, or very nearly so.

TABLE III

BACK VERTEX POWERS OF TRIAL LENSES MADE TO THE OPTICAL SOCIETY'S STANDARDS

Marked Power (D)	Back Vertex Power (D)	
	Negatives	Positives
10	− 9·97	+ 9·97
11	−10·96	+10·96
12	−11·95	+11·95
13	−12·94	+12·94
14	−13·94	+13·93
15	−14·93	+14·91
16	−15·92	+15·90
18	−17·90	+17·86
20	−19·87	+19·82

For convenient reference, the back vertex powers of lenses from 10·00 D upwards made in accordance with the Optical Society's Standards have been computed from the data given in the original report and are shown in Table III. The small discrepancies between the corresponding negatives and positives arise from the fact that central contact is prevented by the slightly different curvatures of the convex and concave surfaces.

(b) *The I.O.O.–A.W.M.O. Standards* (1927)

Recommendations covering trial case lenses were published in 1927 by a Joint Committee of the Institute of Ophthalmic Opticians and the Association of Wholesale and Manufacturing Opticians, set up in 1922 to review the earlier work of the Optical Society in this and other ophthalmic fields.

The report of this Committee advocated plano-convex and concave spheres of reduced aperture (25 mm.). It was clearly the intention that the positives should be placed with the plane surface next to the eye, yet the Committee recommended that both positives and negatives should be numbered according to their *equivalent* power. On this basis, the positives continued to neutralise the corresponding negatives but a serious discrepancy was introduced.

The equivalent power of a plano-spherical lens is the same as the vertex power measured at the curved surface. No problem arises with the negatives. These would normally be placed with their curved surface next to the eye and in this position the marked power is exactly the same as the back vertex power. On the other hand, assuming the positives to be placed with the plane surface next to the eye as the Committee intended, the marked power then represents the front vertex power. Only if the lens were turned with its curved surface towards the eye would its marked power agree with the back vertex power.

Table IV shows the discrepancies which arise in the higher powers from the system of numbering adopted. The figures in the end column were computed on the basis of the standard centre thicknesses tabulated in the Committee's report.

TABLE IV

BACK VERTEX POWERS OF POSITIVE TRIAL LENSES MADE TO THE I.O.O.–A.W.M.O. STANDARDS

Marked Power (D)	Centre Thickness (mm.)	Back Vertex Power (D)	
		Curved surface to eye	Plane surface to eye
+10	2·75	+10·00	+10·18
+11	3·0	+11·00	+11·24
+12	3·0	+12·00	+12·29
+13	3·25	+13·00	+13·37
+14	3·25	+14·00	+14·43
+15	3·5	+15·00	+15·53
+16	3·5	+16·00	+16·61
+17	3·75	+17·00	+17·74
+18	4·0	+18·00	+18·89
+19	4·25	+19·00	+20·06
+20	4·5	+20·00	+21·25

Trial cases of the type recommended in these standards and numbered according to their equivalent power have been made by several firms, most of which have reduced the effective aperture to 20 mm. or so. For this reason the positives would probably tend to be thinner than proposed by the Committee, which would have the effect of reducing the difference between the front and back vertex powers. Even so, the differences would still be appreciable. For example, if the +20·00 D lens were made 1·0 mm. thinner than suggested (3·5 instead of 4·5 mm.) the vertex power measured at the plane surface would still be as high as +20·96 D.

To overcome this difficulty, some manufacturers have ignored the Committee's intention and made a practice of engraving the rims so that the curved surface of the positives is placed next to the eye.

2. EXISTING TYPES OF TRIAL CASE LENSES

The following types of spherical trial case lenses are all in current production in this country:

1. Full-aperture symmetrical lenses to the Optical Society's standards.
2. Thin symmetrical lenses of 28 mm. aperture, numbered on the basis recommended in the Optical Society's standards.
3. Reduced-aperture plano-form lenses, numbered according to their equivalent power, the positives engraved so as to place the plane surface next to the eye.
4. The same as (3), but the positives engraved so as to place the curved surface next to the eye.
5. Reduced-aperture (28 mm.) plano-form lenses, the positives engraved so as to place the plane surface next to the eye but with a back vertex numbering throughout.

3. SYSTEM OF NUMBERING

With the exception of No. 3, all the types of trial case lenses enumerated in the previous paragraph may be considered as conforming to a back vertex numbering. This is a particularly fortunate circumstance because an essential requirement of the back vertex system is that all lenses including trial case lenses should be numbered on this basis, whatever form they may take.

Our previous recommendation on the adoption of back vertex measurement carries with it, as a logical consequence, the added recommendation that in future *all* trial case lenses should be numbered accordingly.

4. LENS FORM AND APERTURE

(a) *Factors Considered*

The form in which trial lenses are made has a direct bearing on

- (i) their effective power when used in sphero-cylinder combinations,
- (ii) their effective power in near vision,
- (iii) their aberrations, especially oblique astigmatism and distortion.

Much importance need not be attached to the last of these factors because care is normally taken in testing to ensure that vision is directed through the centre of the lenses. The other factors, however, are worthy of a detailed analysis.

(b) *Discrepancies of Effective Power*

Because of the thickness of the lenses and their separation in the trial frame, the dioptric effect of a trial lens combination is not always deducible to a sufficient degree of accuracy from the marked powers of the lenses. The following discrepancies can arise, using that term to indicate a difference between the actual focal effect and the approximate value derived from the assumption of thin lenses in contact.

(i) *Distant Vision: Effective Cylindrical Power.*—It may be assumed that the trial lens combination most frequently employed would consist of a spherical lens with a cylinder in front of it. In the axis meridian, the cylinder can be considered to act as a parallel plate, so that, for distant vision, the effective power of the sphere is unchanged. On the other hand, the effective power of the cylinder varies according to the power, form, and thickness of the combining sphere. To give a numerical example, if a − 4·00 D cylinder were placed in front of a + 18·00 D sphere of the full-aperture symmetrical type, the back vertex power of the combination would be approximately + 18·00 sph. − 4·25 cyl.

(ii) *Near Vision: Effective Cylindrical Power.*—It may be demonstrated that the change imposed on the vergence of a pencil of light on its passage through a lens varies with the initial vergence of the pencil. For this reason, the discrepancies of effective power which arise when the incident light is parallel differ from those arising in near vision.

For example, assuming near vision at 1/3 metre, an axial pencil traced through the trial lens combination specified in the previous paragraph (i) could be shown to emerge with a vergence of approximately + 14·80 sph. − 4·12 cyl. Hence the effective cylindrical power of the combination is 0·12 D weaker for near than for distant vision but is still 0·12 D stronger than the nominal (marked) power.

Some graphs showing the variations in effective cylindrical power for various trial lens combinations of different types are presented in Figs. 1 to 4. A more detailed explanation of these graphs will be given in a later paragraph.

(iii) *Near Vision: Error of Mean Power.*—The example just given serves also to show that in near vision the effective power of the spherical as well as of the cylindrical element may undergo an appreciable change. It has been thought appropriate to express this discrepancy as an error of mean power calculated in the following manner.

The mean power is the average of the two principal powers or the spherical plus half the cylindrical power. Since the object vergence corresponding to 1/3 metre is − 3·00 D, the image vergence for the trial lens combination under discussion would be + 15·00 sph. − 4·00 cyl. if lens thicknesses and separations were ignored. The mean vergence would hence be + 13·00 D. Assuming, however, that the actual image vergence is + 14·80 sph. − 4·12 cyl. as previously stated, the mean vergence is really + 12·74 D. The discrepancy may be expressed as an error of mean power, amounting to − 0·26 D.

It may be remarked that similar errors of effective power are exhibited by single lenses: in general, one cannot add the object vergence to the back vertex power of a lens to obtain the image vergence at the back surface. For example, a meniscus correcting lens of back vertex power + 6·00 D and of average thickness would show an error of approximately − 0·25 D when used in near vision at 1/3 metre. That is to say, the image vergence at the back surface would be actually +2·75 D instead of the nominal (thin lens) value of + 3·00 D.

A graph designed to show the general pattern of mean power errors, both for trial lens combinations and for typical correcting lenses, is presented in Fig. 5.

(c) *Two Principles of Design*

Two different principles of design, each of which in different ways takes account of effectivity, are worthy of study.

(i) *The Principle of Direct Substitution*.—This principle was advocated in 1924 by W. Swaine in a paper entitled " A Suggested Standard Trial Case and Simplification in Ophthalmic Policy " (Trans. Opt. Soc. Vol. XXV, No. 2). In this paper Mr. Swaine summarised his views in the following words:

> " The fundamental idea of the trial case is the estimation of refractive error by a process of direct substitution. In order that a substituted spectacle lens shall reproduce the trial lens as far as distance vision is concerned, it should have the same back vertex power. . . . On the other hand lenses of different forms but equal back vertex power are *not* equally effective in near vision. . . . As the question is inevitably one of compromise, a trial lens should conform in shape and thickness to the most frequent form of lens used."

On this basis Mr. Swaine advocated plano-form spherical lenses made to a back vertex numbering, the positives being of approximately the same thickness as mass-produced flat lenses of corresponding power. In view of the subsequent increase in the popularity of lenticular lenses, the centre thicknesses proposed for the higher powers may now be thought excessive. Nevertheless, Fig. 5 shows that this series (D) approximates most closely in its mean power errors to those of typical correcting lenses.

As the other graphs reveal, this series exhibits considerable errors of effective cylindrical power if the cylinder is placed in front of the sphere when the latter is of strong positive power. These errors could admittedly be eliminated by placing the cylinder behind the sphere—as the principle of direct substitution would demand—but that would lead to discrepancies in the effective spherical power.

(ii) *The Principle of " Additive Vertex Powers "*.—Trial cases based on this principle have been produced by two of the leading American manufacturers. The spherical lenses are plano-convex and concave. They are of uniform centre thickness irrespective of power and are invariably placed with the curved surface next to the eye. The cylinders are placed in a front cell and are so mounted in their rims as to ensure a uniform air separation. Theoretically, this combination reduces itself to an infinitely thin cylinder at a fixed distance in front of an infinitely thin sphere. It is therefore possible so to compensate the cylindrical curves that the back vertex power of any sphero-cylinder combination is given exactly by the marked powers of the lenses.

By this means, errors of cylinder effectivity are eliminated for distant vision. In near vision, however, the effective cylindrical powers would inevitably be weaker than the marked powers. Moreover, it is a curious characteristic of this design that its mean power errors in near vision are much lower than those of most correcting lenses of corresponding power.

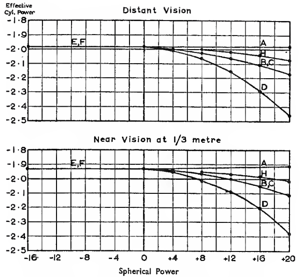

FIG. 1. Effective power of −2·00 D cylinder in front of various spherical lenses.

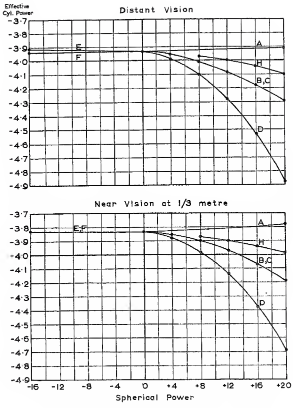

FIG. 2. Effective power of −4·00 D cylinder in front of various spherical lenses.

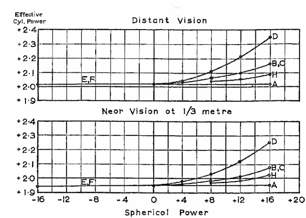

FIG. 3. Effective power of +2·00 D cylinder in front of various spherical lenses.

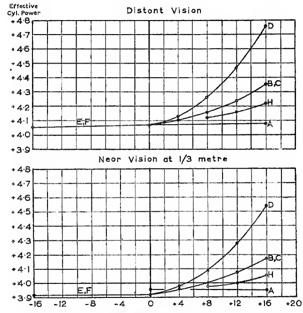

FIG. 4. Effective power of +4·00 D cylinder in front of various spherical lenses.

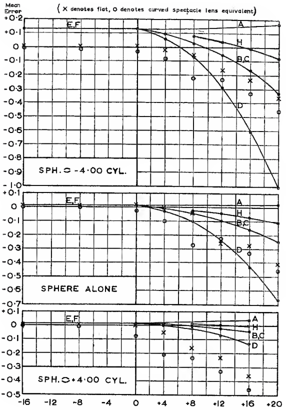

Fig. 5. Error of Mean Power in near vision of various trial lens combinations.

(d) *Comparison of Different Trial Lens Forms*

Before pursuing this discussion it would perhaps be advantageous to revert to the graphs, which have been plotted from the results of extensive computations.

In these graphs, the various lens forms chosen for comparison have been given distinguishing letters as set out below. It was assumed that each individual lens was numbered to give its back vertex power, in accordance with the recommendation made in an earlier paragraph.

A : Plano-convex, curved surface to eye, the thickness suitable for a 20 mm. lens aperture.

B : Equi-convex, the lenses conforming substantially to the Optical Society's 1908 standards but with the surface powers slightly modified to give a true back vertex numbering (i.e., not the back vertex powers shown in Table III).

H : A hypothetical series of equi-convex lenses, differing from type B in having thinner substances suitable for a 20 mm. lens aperture.

C : Plano-convex, plane surface to eye, the thickness suitable for a 20 mm. lens aperture.

D : Plano-convex, plane surface to eye, similar to type C but with the (greater) thicknesses proposed by W. Swaine in his paper to the Optical Society, reference to which has already been made.

E : Equi-concave.

F : Plano-concave, curved surface to eye.

In carrying out the computations it was necessary to calculate a value for the separation between the two lenses of each combination. The assumption was made that the cells in the trial frame would be 5 mm. apart, as in the type of trial frame most widely used. Full details of the thicknesses and surface powers of the lenses, together with other relevant data, will be found in the appendix to this report.

Fig. 1 shows how the effective power of a − 2·00 D cylinder varies according to the spherical lens with which it is combined, both for distant vision and for near vision at 1/3 metre. Fig. 2 gives the same information for a − 4·00 D cylinder, while Figs. 3 and 4 show the corresponding graphs for a + 2·00 D and a + 4·00 D cylinder respectively.

Fig. 5, consisting of three separate graphs, shows how the error of mean power in near vision varies with the power of the sphere and also with the power of the cylinder with which it is combined. In considering these errors of mean power it should be remembered that the mean power of the correcting lens itself, when used in near vision, may show a discrepancy of the same kind, a typical example having been given in an earlier paragraph. Some representative values both for "flat" and "curved" lenses have been indicated in Fig. 5 for comparison with the corresponding error of the trial lens combination.

The trial lens combination has hitherto been assumed to consist of only two lenses—a cylinder placed in front of a sphere. When testing for near vision it is equally likely that the distance correction would be left *in situ* and a third lens placed in the foremost cell to provide the reading addition. Calculations made for a few typical combinations of this kind suggest that their error of mean power would not differ to any appreciable extent from that of the equivalent two-lens combination using lenses of the same type.

(e) *Survey of Results*

It is hoped that the graphs are sufficiently self-explanatory to obviate the need for lengthy comment on our part. We offer only a few observations on the range of convex spherical powers: in the concave range the graphs show that the form of the lens is immaterial.

Type A (Plano-convex, curved surface to eye).—This form of lens, which is one of those in current production, is the same as that employed in the American additive vertex power trial sets. The graphs relating to type A will therefore furnish a good idea of the general performance of this latter design.

Type B (Equi-convex, substantially to the Optical Society's standards), and *Type C (Thin plano-convex, plane surface to eye)*.—Unlike type B, type C is not in current production. It was included in the computations to show the performance of a series of thin plano-convex lenses with the plane surface next to the eye, made to a *back* vertex numbering.

The differences between the numerical results obtained with these two series proved to be so slight that no attempt has been made to distinguish between them in the graphs. The explanation for so remarkable a similarity is that the greater thickness of type B is offset by the steeper curvature of type C.

Type H (Thin equi-convex).—This represents a series of equi-convex lenses of thickness comparable to series A and C, which means that they are appreciably thinner than any existing equi-convex set. Their performance was investigated because it was thought that they might provide a reasonable compromise between Series A and B, particularly in regard to effective cylindrical power.

Type D (Thick plano-convex, plane surface to eye).—This series, suggested by Mr. Swaine, has already been discussed in an earlier paragraph.

Variations in Form and Thickness.—A comparison of the graphs for series A, H, and C, which are of similar thickness, shows the effect of lens form on the various errors and discrepancies considered. Similarly, a comparison of the graphs for series B and H, and C and D, shows the effect of increasing the thickness without change of form.

(f) *Recommendations*

(i) *Lens Design*.—We feel unable to recommend, as an exclusive standard, any of the existing series of trial lenses, because none of them is clearly superior to all others in every respect.

We believe that the ideal trial case would be designed to reconcile the principle of direct substitution with that of additive vertex powers. The essential features of such a set would be as follows:

(*a*) in distant vision, accurate additive vertex powers for all sphero-cylinder combinations.

(*b*) in near vision, negligible errors of effective cylindrical power, but errors of mean power comparable to those of typical correcting lenses.

As demonstrated by the graphs, these requirements cannot be met simultaneously when the cylinder is placed in front of the sphere.

We accordingly recommend manufacturers to consider the possibilities of a trial case designed on the following basis.

In brief, the convex sphericals would be made in plano-form with the curved surface away from the eye and placed *in front of* the cylinder, the latter being turned with its curved surface towards the eye. The adjacent surfaces both being plane, the two lenses could be held quite closely together with a constant separation. The cylinders would be made of uniform thickness irrespective of power and sign. If the front surface of each spherical lens were compensated to allow for the two lens thicknesses and the separation between them, the back vertex power of any combination of sphere and cylinder would be the exact sum of the marked powers. Moreover, the effective power of the cylinder would be unchanged in near vision and, furthermore, the errors of mean power would closely approximate to those of typical correcting lenses of like power.

In making such a set it would not be necessary to impose severe restrictions on the effective aperture of the high-powered convex spherical lenses, thereby removing one objection which has been urged against the existing design of trial sets based on additive vertex powers.

We appreciate that it would be necessary to devise some means of reading the axis if the cylinder were placed behind the sphere, but this does not seem to us an insuperable difficulty.

(ii) *Basis of Numbering.*—It is to be noted that the adoption of a back vertex numbering would, with lenses of type C or D, entail as a consequence that the front vertex or neutralising power of the positives differed from the marked power.

When this form is supplied, we recommend that the front vertex power of the positives should be stated by the manufacturer, preferably in the form of a table affixed to the case, so that the lenses can be used for neutralising if required. This would also apply to trial sets of the design which we recommend.

(iii) *Use of Focimeter.*—The attention of practitioners is drawn to the fact that by means of a focimeter the back vertex power of any combination of lenses in a trial frame can be accurately determined while *in situ.* Discrepancies in effective power arising from whatever source, including a front vertex numbering where this applies to certain existing trial sets, can thereby be eliminated.

5. PRISM UNITS

For many years it has been usual in this country to number plano prisms according to their deviation expressed in prism dioptres (Δ). As the prism dioptre is so convenient both in theory and in practice and is now so well-established, we recommend that it be adopted exclusively as the unit of prism power. We further recommend that, to prevent confusion, the use of older units such as degrees of apical angle and degrees of deviation be discontinued.

We know that the prism dioptre is open to the theoretical objection that it is not truly a unit inasmuch as it is not strictly additive, and we agree that from this point of view the centrad (∇) would be a better choice. In practice the difference between these two units is so slight as to have no clinical significance. Although it is the more scientific unit, the centrad has not hitherto succeeded in establishing itself, and we feel that any attempt to impose it at this stage would have only a doubtful chance of success.

The deviation of a plano prism is normally understood to refer to its minimum deviation, which occurs when light passes through it in a symmetrical path. For ophthalmic prisms, however, we recommend that the deviation be measured for light incident normally at one surface; firstly, because it is customary to mount trial case prisms with one face parallel to the plane of the rim, and, secondly, because normal incidence is better adapted to the various methods in use for checking plano prisms to a high degree of accuracy.

For the convenience of manufacturers and others, Table V sets out the apical angle (for ophthalmic crown glass of mean refractive index 1·523) and minimum deviation of a range of trial case prisms numbered as recommended above to show their deviation in prism dioptres for light incident normally at one surface.

TABLE V

MINIMUM DEVIATION AND APICAL ANGLE OF PLANO PRISMS NUMBERED FOR LIGHT INCIDENT NORMALLY AT ONE SURFACE

Marked Power of Prism (Δ)	Deviation for Normal Incidence (Δ)	Minimum Deviation (Δ)	Apical Angle (for n = 1·523)
4	4	3·99	4° 22′
6	6	5·97	6° 31′
8	8	7·93	8° 38′
10	10	9·83	10° 40′
12	12	11·69	12° 40′
15	15	14·44	15° 32′
20	20	18·71	19° 52′

6. DETAILS OF MARKING

In the interests of accuracy we recommend the following method of marking:

(a) *Axis of Cylindrical Lenses*

In addition to any marking on the rim or mount, the cylinder axis to be indicated by two short lines engraved on one surface of the lens itself.

(b) *Base-apex Direction of Prisms*

In addition to any marking on the rim or mount, the base-apex direction to be indicated by two short lines engraved on one face of the prism, the base to be denoted by another line (not necessarily on the lens) at right-angles to this marking.

7. STANDARDS AND TOLERANCES

(a) *External Diameter of Mounts*

There seems to be a certain lack of uniformity at present, some manufacturers having adopted 37·5 mm. and others 38 mm. as the standard external diameter of their trial lens rims. We therefore recommend manufacturers of trial frames to ensure that the cells are made large enough to accommodate a 38 mm. rim.

In making this recommendation we do not wish to exclude the introduction of a smaller size of mount if it is felt that improvements in the design of trial frames would thereby be facilitated.

(b) *Pinhole Discs and Stenopaic Slits*

We recommend that the standard size of aperture be 1 mm., supplemented by such larger sizes as may be thought desirable.

(c) *Lens Material and Surfaces*

We recommend that trial case lenses should conform to the following specification:

All lenses to be free from defects such as bubbles, veins, and other internal irregularities which can be observed by accepted methods of inspection, and, except for tinted lenses, to be made from commercial white ophthalmic glass or other suitable material of proven quality.

All lens surfaces to be well-polished and free from defects such as waves and similar errors of figure, chips, scratches, and other abrasions which can be observed by accepted methods of inspection. The lenses to be mounted securely, but to show no significant strain when examined in a polariscope.

(d) *Tolerances*

In considering the tolerances which might be permitted we have thought it justifiable to assume that they should be rather narrower than those which would be appropriate to ophthalmic lenses made to prescription. On the other hand, unreasonably close tolerances would merely add to the cost without bringing any benefit either to patient or prescriber.

After consideration we have agreed to put forward the following recommendations:

(i) *Lens Powers*

Range of Powers	*Tolerance*
Plano to 1·00 D	0·03 D
over 1·00 to 6·00 D	0·06 D
over 6·00 to 15·00 D	0·12 D
over 15·00 D	0·18 D

(ii) *Cylinder Axes*

Cylinder Power	*Tolerance*
0·12 D	3°
0·25 to 1·75 D	1¼°
over 1·75 D	1°

(iii) *Optical Centration*

Range of Powers	*Tolerance*
0·12 to 0·50 D	2 mm.
over 0·50 to 2·00 D	1 mm.
over 2·00 D	0·5 mm.

(iv) *Prism in Axis Meridian of Cylinders.*—Any prismatic effect in the axis meridian of a cylinder not to exceed 0·2 △.

(v) *Plano Prisms*

Power of Prism	*Tolerance on Power*	*Tolerance on Base-apex Direction*
Up to 6 △	0·12 △	2°
over 6 △	0·25 △	1°

(vi) *Crossline (Centring) Discs.*—The intersection of the crosslines to be within 0·5 mm. of the true geometrical centre.

(vii) *Maddox Rods or Grooves.*—Any prismatic deviation in a direction at right-angles to the projected streak not to exceed 0·2 △.

8. STANDARD CONDITIONS FOR LABORATORY TESTING OF LENSES

For many years the National Physical Laboratory has provided a service to manufacturers and others by measuring to a high degree of accuracy the power of lenses submitted for test.

At the instance of the Laboratory, and as a result of its past experience, we have considered whether trial case lenses should in future be tested under certain standard conditions.

(a) *Choice of Wavelength.*—Because of the variation in refractive index according to wavelength, the power of a lens made from hard crown glass varies by approximately 2 per cent. over the range of the visible spectrum. For precise measurement of power, a particular wavelength must therefore be specified. As it has become the standard practice to base the " mean refractive index " of glass or other material on the yellow d line of the helium spectrum (corresponding to a wavelength of 5875·6 Angstroms) we recommend that the power of trial case lenses and prisms be expressed and measured for this same wavelength.

(b) *Aperture Used in Measurement of Focal Length.*—Using the Rayleigh limit of one-quarter wavelength ($\lambda/4$) as the criterion, the depth of focus of a lens with negligible spherical aberration can be shown to be equivalent to a power variation of

$$\pm \lambda/2\,y^2$$

where y is the semi-aperture of the lens, λ and y both being in metres. This expression shows that the uncertainty in the position of the best focus is reduced by employing as large an aperture as possible. On the other hand, if the aperture is unduly increased the effects of spherical aberration become more pronounced to the detriment of accurate focusing.

After full consideration we have concluded that nothing would be gained by specifying one particular test aperture for all trial lenses. We accordingly recommend that in testing such lenses the National Physical Laboratory should continue to use whatever aperture is best suited to the accurate determination of the paraxial power of each individual lens.

9. CALIBRATION AND USE OF FOCIMETERS

In choosing the d line of the helium spectrum as the basis of power measurement we noted that most focimeters incorporate a greenish filter with its peak transmission at a somewhat shorter wavelength. The maximum discrepancy so arising, which would occur at the extreme limit of the power scale, would be of the order of 0·10 D assuming the instrument to read up to 25 D. It is believed that the design of most focimeters would permit the discrepancy to be eliminated by means of a slight adjustment to the collimating lens system. The attention of manufacturers is drawn to the desirability of checking each instrument with test lenses of known vertex power for the helium d line.

Another possible source of error in measuring high-powered lenses with a focimeter ought perhaps to be mentioned. The theory of the instrument requires that the vertex of the lens under test should lie in a fixed plane; if, however, the lens is held against a fixed annular stop, the vertex of the surface will depart from the plane of the stop by a variable amount depending on its curvature. As a result, the power so recorded will not be the true vertex power. Errors of measurement arising from this source are seldom likely to exceed 0·12 D even on the highest powers, but in relation to the tolerances allowed this figure cannot be regarded as negligible.

10. REFRACTING UNITS (REFRACTOR HEADS)

Although these instruments do not come within our terms of reference, we feel it desirable to draw the attention of manufacturers of refracting units to the principles of numbering and tolerances recommended in this report.

Summary of Recommendations

PART I

Measurement of Lens Powers

That the back vertex system of measuring lens powers be adopted (paragraph 4).

Recording of the Vertex Distance

That the " vertex distance " or distance from the cornea of the back vertex of the trial lens or lens combination be recorded as part of the prescription when the power exceeds 5·00 dioptres or when the position of the spectacles dispensed is likely to be significantly different from that of the trial lenses (paragraph 5).

PART II

Numbering of Trial Case Lenses

That all trial case lenses should be numbered to denote their back vertex powers (paragraph 3).

That consideration be given to an " additive vertex power " trial case of a modified design (paragraph 4).

That the front vertex or neutralising power of a trial lens should be stated by the manufacturer when it differs from the marked (back vertex) power (paragraph 4).

Numbering of Plano Prisms

That the prism dioptre be standardised as the unit of prism power and that the use of other units be discontinued.

That the deviation of plano prisms be measured for light incident normally at one surface (paragraph 5).

Marking of Plano Prisms and Cylindrical Lenses

That in addition to any markings on the rim or mount the base-apex direction of prisms and the axis of cylindrical lenses be indicated by two short lines engraved on one surface of the lens; and the base of prisms be denoted by a line (not necessarily on the lens) at right-angles to this marking (paragraph 6).

Standards and Tolerances

That trial case lenses and accessories should conform to the standards and tolerances set out in our report (paragraph 7).

Testing of Lenses

That the power of trial case lenses and prisms be expressed and measured with respect to light of wave length corresponding to the yellow d line of the helium spectrum (paragraph 8).

That focimeters be calibrated for light of this same wavelength, and that attention be paid to the position of the lens under test (paragraph 9).

(*Signed*) STEWART DUKE-ELDER (*Chairman*)
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APPENDIX

Details of Trial Lenses used as a basis for Figs. 1 to 5

(*See Part II, para.* 4)

Spherical Power	Details	Type A	Type B	Type C	Type D	Type H	Type E	Type F
−16·00	F_1						−8·01	Plano
	F_2						−8·01	−16·00
	t						0·5	0·5
	d						3·6	3·6
−8·00	F_1						−4·00	Plano
	F_2						−4·00	−8·00
	t						0·6	0·6
	d						3·6	3·6
Plano	F_1	Plano	Plano	Plano	Plano		Plano	Plano
	F_2	Plano	Plano	Plano	Plano		Plano	Plano
	t	1·4	1·4	1·4	1·4		1·4	1·4
	d	3·6	3·6	3·6	3·6		3·6	3·6
+4·00	F_1	Plano	+2·00	+3·98	+3·97			
	F_2	+4·00	+2·00	Plano	Plano			
	t	1·9	2·8	1·9	2·6			
	d	3·55	2·9	3·15	2·8			
+8·00	F_1	Plano	+3·98	+7·91	+7·83	+3·99		
	F_2	+8·00	+3·98	Plano	Plano	+3·99		
	t	2·2	3·8	2·1	4·2	2·2		
	d	3·6	2·4	2·9	2·1	3·2		
+12·00	F_1	Plano	+5·94	+11·77	+11·48	+5·97		
	F_2	+12·00	+5·94	Plano	Plano	+5·97		
	t	2·6	4·9	2·5	5·8	2·6		
	d	3·6	1·85	2·5	1·4	3·0		
+16·00	F_1	Plano	+7·87	+15·53	+14·85	+7·94		
	F_2	+16·00	+7·87	Plano	Plano	+7·94		
	t	3·0	6·4	2·9	7·4	3·0		
	d	3·6	1·1	2·1	0·7	2·8		
+20·00	F_1	Plano	+9·75	+19·17	+17·89	+9·89		
	F_2	+20·00	+9·75	Plano	Plano	+9·89		
	t	3·4	7·8	3·3	9·0	3·4		
	d	3·6	0·4	1·7	0·1	2·6		

F_1 = front surface power (in dioptres).
F_2 = back surface power (in dioptres).
t = centre thickness of lens (in mm.).
d = estimated separation between cylinder and sphere (in mm.).

(*Note:* These figures were adjusted for convex cylinders of type A, which are placed with the curved surface nearer the eye).

Concave Cylinders: centre thickness 1·4 mm.

Convex Cylinders: same centre thickness as corresponding sphericals.

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